THE USE AND TRANSFER OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS TECHNOLOGY TO DETECT PHYLLOXERA STRESS IN VINEYARDS, EARLY RESULTS.

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ABSTRACT

This paper discusses the development and transfer of remote sensing and geographic information system (GIS) analysis from NASA Ames Research Center and university partners to Robert Mondavi Winery for the detection of vine damage caused by phylloxera infestation. Field, aircraft, and satellite-based remote sensing data are being analyzed to detect phylloxera biotype B both before and after visual symptoms are apparent in Napa Valley, California. A GIS is used to understand the spatial and temporal distribution of the phylloxera infestation. Initial results are promising; remotely sensed data were able to provide pre-visual discrimination of phylloxera infestations based on data collected in 1993.

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INTRODUCTION

The work presented here results from the Grapevine Remote sensing Analysis of Phylloxera Early Stress (GRAPES) project. A multi-disciplinary project team (Table 1) is researching and applying remote sensing and geographic information systems techniques for operational use by vineyard managers.

The scope of the project includes detecting the early stages of the infestation, understanding the spread, quantifying the effects, and documenting the introduction of phylloxera into portions of the Napa Valley in California. Phylloxera, an aphid-like parasite, kills grape vines by feeding on their roots and making the roots vulnerable to secondary infections. A new phylloxera strain has emerged, killing vines planted on a rootstock that dominates the Napa and Sonoma County, California vineyards. Approximately seventy percent of these premier vineyards, forty to forty five thousand acres, are planted on *Araman x Rupestris* #1 (AxR #1) rootstocks, and are susceptible to being destroyed by phylloxera.

The collaborative government, industry, and university team works shoulder-to-shoulder in the field, laboratory, and computer room. Each organization brings unique talents and perspectives to the work. The overall goal of the project is to help 'spin out' NASA based technology to US industry which can use these tools to help solve current problems.

BACKGROUND

Grape phylloxera, *Daktulosphaira vitifoliae* (Fitch), is currently causing vine decline in California vineyards approximately 100 years after the soil-born aphid first caused the rapid loss of vines in Europe and the United

States. In the late 1800's, biotype A phylloxera caused the decline of "own rooted" *Vitis vinifera* grape vines in France, Italy, and California. The rootstock AxR#1 was found to tolerate low levels of biotype A phylloxera and became the most widely-used rootstock in California. The current phylloxera-driven decline of grape vines in California is due to a newly discovered strain of phylloxera, biotype B (Granett, Goheen, Lider, 1987), which multiplies almost as rapidly on AxR #1 rootstock than on "own-rooted" or other vines. Approximately 65 to 70% of the more than 65,000 acres of vines in Napa and Sonoma counties were planted on AxR #1 rootstock, and are therefore susceptible to biotype B phylloxera.

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Table 1: Organizations participating in the Grapevine Remote sensing Analysis of Phylloxera Early Stress (GRAPES) Project.

Phylloxera is a soil-residing aphid-like insect that feeds on and eventually destroys the root system and kills susceptible grape vines. The infestation of vines is not visible until approximately two to three years after the insect has begun feeding on the roots when the vine is severely impaired in its ability to support fruit and vegetative growth. Visual symptoms of phylloxera-caused decline of vines include the marginal burning and drying of leaves, stunting of shoot growth and collapse of fruit in the middle to late part of the growing season. The fruit of such severely affected vines does not fully mature and is not suitable for premium wine production.

Because there are no accepted, reliable insecticides capable of controlling or eradicating phylloxera, the vineyards will eventually have to be replanted on resistant rootstocks. Grape vine breeding programs successfully utilized native American grape vines to combat the phylloxera-driven vine decline of France in the late 1880's. Many areas of the Unites States have native populations of grape vines that have co-evolved with phylloxera biotypes. This naturally occurring tolerance to phylloxera is currently the only known method by which phylloxera can be successfully combated. Simple genetic crosses of the native grape vines over 100 years ago have provided commercially available plant materials that are now in use in the fight against phylloxera. The phylloxera tolerant rootstocks are planted with the susceptible *Vitis vinifera* cultivar such as Chardonnay or Cabernet Sauvignon grafted to it. Vines require approximately three to five years to recover grape production following the replanting of vineyards.

It should be noted that while phylloxera causes serious problems for wine growers, it does not pose any human health threat whatsoever. In order to maintain high quality wine characteristics, wine makers do not harvest poorly developed fruit from phylloxera infested fields. There are no related human health issues.

To verify the presence of phylloxera, one must dig at the base of the vines and take root samples; however, this is time consuming, costly, and potentially damaging to the root system. In practice, this procedure is limited to very small areas of exploration. Color-infrared (CIR) aerial photography has been widely used for several years to assess damage to vineyards due to phylloxera and measure its rate of spread (Wildman, Nagoaka, and Lider 1983) and (Wildman, Granett, and Goheen 1988). Although aerial photography provides an abundance of information over large regions, there is much that is still unknown about phylloxera. Wine growers would like to be able to identify those factors that cause the spread of phylloxera as well as detect the presence of phylloxera as early as possible, to develop crop management and forecasting plans.

The GRAPES project is focused on the need for early detection of phylloxera and the identification of factors that affect its spread. The three year project is jointly funded by NASA's Office of Advanced Concepts and Technology and Robert Mondavi Winery (RMW) to develop the tools and techniques for early stress detection using remote sensing and geographic information system technology. This technology will then be transferred to the grape and wine industry for commercial application. The project has four well-defined goals with associated tasks. The work and results to date for each of the four tasks will be described in this paper.

CHARACTERIZATION OF THE SPECTRAL RESPONSE OF PHYLLOXERA-INDUCED STRESS

One goal of the project is to detect the presence of phylloxera before stress is visibly apparent by investigating the spectral and chemical response of grape leaves to stress due to the infestation of phylloxera. This task involves relating leaf level data collected in the field from vines with known phylloxera population levels to canopy level data collected from aircraft-based sensors for a larger test site area.

Remote sensing technology has been used in studies to assess the response of plants to numerous stress factors. Nitrogen and other nutrient deficiencies reduce the concentration of chlorophyll pigment, resulting in spectral differences between healthy and stressed plants (Thomas and Oerther, 1972), (Tsay, Gjerstad, et. al. 1982). Nutritional deficiencies in vines resulting from phylloxera damage to the roots, and the subsequent changes in the vine's physiology and chemistry, can be used for early detection of vine infestation. The first symptom of nitrogen and potassium deficiency in plants is the yellowing (chlorosis) of leaves due to reduced chlorophyll content. In addition, when nitrogen is lacking, plants can produce other pigments to further change the spectral response of leaves. Variations in plant biophysical parameters such as leaf area index (LAI) have also been used to spectrally separate healthy from stressed plant canopies (Knipling, 1970).

Field measurements of vine biophysical and biochemical parameters have been combined with spectral information obtained at individual leaf and whole canopy scales. Leaves were collected monthly between May and October from eleven different plots located throughout an eleven acre study site vineyard (Figure 1). The plots were grouped into categories, based on the status of above ground vine damage and below ground phylloxera population levels (determined by physical excavation of vine roots) at the onset of the field work in May, 1993. Category 1 (plots 1, 2 and 3) contained vines that had phylloxera and showed vine decline from phylloxera. Category 2 (plots 4, 5 and 6) contained vines that had phylloxera in the ground, but showed no visible symptoms. Category 3 (plots 7,8 and 9) contained healthy vines that did not have phylloxera in the ground. In category 4 (plots 10 and 11), stress was induced by back hoeing adjacent to the vines to physically injure roots to imitate phylloxera induced root loss. A Minolta SPAD-502 chlorophyll meter was used in the field to estimate the chlorophyll content of individual leaves. The leaves were then transported to NASA Ames to collect spectral measurements using a NIRS spectrophotometer and leaf area measurements using a leaf area meter. The leaves were then dried to constant weight and analyzed for nitrogen, phosphorus and potassium concentration.

In order to obtain spectral information at the whole canopy scale, an aircraft-based sensor, CASI (Compact Airborne Spectrographic Imager), was flown in July 1993 over the subject study sites. The CASI data are being analyzed to estimate plant canopy biochemical content, specifically, chlorophyll and nitrogen. The relationship between the spectral information from CASI imagery and the leaf-level spectral data is being analyzed to determine if vines that have phylloxera can be detected with airborne remote sensing data before symptoms become apparent. In addition to utilizing CASI for early detection of phylloxera, its spectral and spatial resolution enabled team members from Mondavi winery to see the effects of vine stress due to phylloxera infestation in vineyards better than with color-infrared aerial (CIR) photography. Computer image processing techniques common to remote sensing digital analysis, such as principal component analysis, band ratioing, and multispectral classification enhanced infested areas much more obviously than standard CIR photography products.

After preliminary analysis of the 1993 data collected during the summer months, some promising results have emerged. The leaf reflectance of severely infested vines in Category 1 were clearly spectrally separable from Categories 2 and 3 throughout the entire season. Categories 2 and 3 were distinguishable late in the season, during September and October (Figure 2). Results from this data will be used to further refine the sampling strategy for the 1994 growing season.

ANALYSIS OF THE SPATIAL AND TEMPORAL SPREAD DYNAMICS WITH A GEOGRAPHIC INFORMATION SYSTEM

A second goal of the project is to understand the spatial and temporal distribution of phylloxera infestation and assess the risk to other areas of future infestation. This task includes identifying environmental and cultural factors that influence the spread of phylloxera.

A geographic information system (GIS) is employed to understand the spatial and temporal distribution of the infestation and to assess the risk of future infestation to other grape growing areas. Relatively little is known about factors influencing the spread of phylloxera. It has been observed that outbreaks appear to be more common in areas with clay soils or soils underlain by hard-pan than areas with sandy soils (Granett, Goheen, Lider, 1987). However, many other environmental factors are suspected to contribute to the likelihood of infestation.

Team members from all five of the participating organizations have worked closely together to identify those factors that are believed to be most important in affecting the existence and spread of phylloxera. Such factors include soil type and characteristics, elevation, predominant wind direction, water table level, cultivation practices, irrigation and drainage, grape variety, row and vine spacing, root stock, row direction and age of fields. An area consisting of approximately 650 acres, managed as 56 field units, was chosen as a study area to investigate the relationships between phylloxera infestation and these environmental factors. Much of the data for the study area has been obtained from an extensive tabular database maintained by the winery and updated on a yearly basis. This tabular data has been input to the GIS, to allow spatial analysis of this data.

In addition to tabular field data, spatial information showing the location of visibly stressed areas due to phylloxera was identified. Low altitude infrared aerial photography covering the study area was used to document the spread of phylloxera from 1987 through 1992 (Figure 3). Areas infested by phylloxera showed stress by diminished vine growth and were easily detected on the photography. Team members from Ames and Mondavi worked together to interpret the aerial photos and delineate infested areas using image processing and a geographic information system at Ames.

After all of the data are collected and entered into the GIS, multivariate statistical analysis will be employed to determine which factors are significantly related to infestation. The same process will be performed for a second study site to further support our findings. Buffer analysis will be employed to determine if proximity to certain linear features such as roads, creeks and rivers, or irrigation lines affect phylloxera spread. Ultimately a "risk map", quantifying relative levels of risk to infestation, will be developed for the entire valley.

MEASURING THE LOSS OF PRODUCTION WITH SATELLITE IMAGERY

Satellite imagery is being used to measure and document land use changes that have occurred over time throughout the Napa Valley. Since 1983, when the first serious outbreaks of phylloxera biotype B were detected, many vineyards have been pulled out of production due to severe vine damage. Some vineyards were replanted, some vineyards lie fallow while growers secure funding to replant, and some areas may have been transformed from vineyard production to other agricultural or urban uses.

Traditionally, interpretation of aerial photos is used to assess land cover change; however, this is a very labor and time intensive process. Satellite imagery is advantageous because the entire study area is covered by one image, while aerial photography requires a mosaic of images. The use of digital satellite imagery with an image processing system automates this process and provides a more efficient way to quantify land cover change. In this project, Landsat Thematic Mapper (30 meter spatial resolution) and SPOT (10 and 20 meter spatial resolution) digital imagery will be analyzed to characterize and quantify the land cover changes that have occurred throughout the valley due to phylloxera infestation between 1983 and 1993.

TRACING THE INTRODUCTION OF PHYLLOXERA TO THE NAPA VALLEY BY PHOTO-INTERPRETATION OF AERIAL PHOTOGRAPHY

The final goal of this project is to understand the introduction of phylloxera biotype B to the Napa Valley by analyzing historical aerial photography. It is unknown whether biotype B was introduced to the Napa Valley at a single location or whether it is a mutation of an existing local population of biotype A. Aerial photography taken at the time biotype B was first discovered in the Valley will help identify the location(s) that were initially infested. This information is important to growers in other areas of the state as they try to quarantine their vineyards to prevent the spread of phylloxera.

In order to fully understand the existence and spread dynamics of phylloxera, the locations of fields within the Napa Valley that were first infested and identified using aerial photography will be entered into the GIS.

The GIS will be used to analyze the relationship between infestation and environmental variables such as soil type and proximity to creeks or rivers.

CONCLUSIONS

Spring and summer of 1993 was the first season of field work for the GRAPES project. Data were collected in the vineyards and analyzed in laboratories at NASA Ames Research Center, U.C. Davis, and Ca. State, Chico. Remotely sensed data, including low altitude (1:8000 scale) and high altitude (1:35,000 scale) aerial photography, digital image data from aircraft-based sensors and satellite imagery, were collected. The first results have been very encouraging and will be used to refine the efforts needed for fieldwork in 1994.

Results indicate that heavily infested areas are easily detected with aircraft-based remote sensing imagery. Early stages of infestation, specifically the pre-visual stage, may be detectable with remote sensing data late in the growing season. Fall identification of pre-visual infestation areas would indicate to vineyard managers which areas of fields need replanting during the winter, or at least where to expect decreased yields during the next growing season if vines are not replaced.

By late 1993, phylloxera biotype B had been found in eight wine growing counties in California. Successful results of this project will not provide a cure or any known alternative to the eventual decline of vines due to phylloxera. It will, however, provide valuable information about the rate and direction of spread of phylloxera and the rate of decline of vineyards. These rates are critical for financial management of the wine businesses. Commercial lenders are unwilling to finance the capital costs of replanting vineyards unless positive cash flow can be projected, which is dependent on crop projections. A financial balancing act is required to manage the required cash investments with the temporary loss of product. The infestation of vineyards with phylloxera B type and subsequent loss of fruit production threatens a shortage of certain grapes, and the loss of market share for California and US wines. It is anticipated that this new source of information will allow improved planning to time critical replanting, helping US companies maintain grape supply and retain market share. It will help identify those vineyards that have the highest risk of infestation throughout California's wine growing regions. It will allow vineyard managers to base decisions on more current, detailed information than they have previously had access to.

A new segment of the agricultural industry will realize the benefits provided by remote sensing data and GIS technologies. A RMW staff member was so intrigued by the use of GIS for this problem that he enrolled in a university class to learn more about the development and use of GIS technology. RMW staff have also begun to explore GIS products and services that are on the market. Several staff members are very encouraged by the power of digital image processing as compared to the passive viewing of CIR photography products. Plans are being made to present project results to a larger audience of the Napa Valley wine industry.

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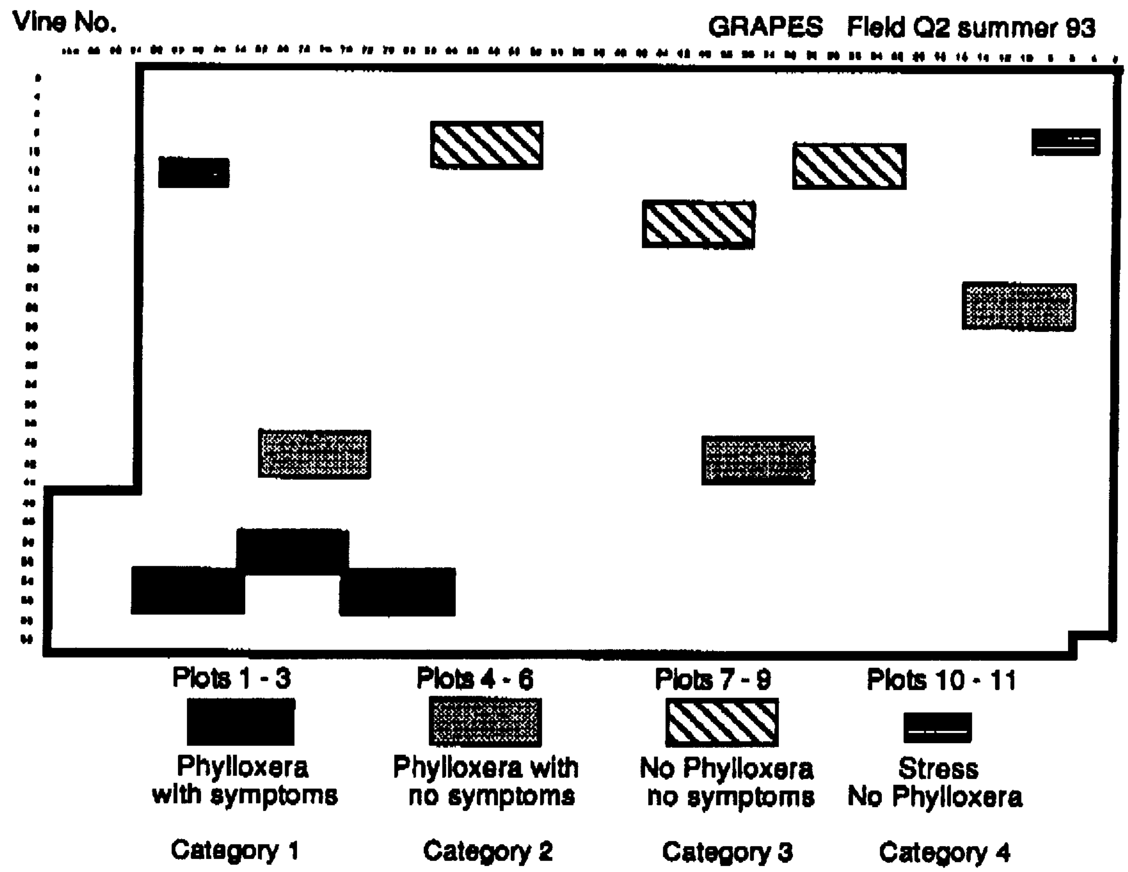

Figure 1: Eleven acre experiment site with four levels of phylloxera infestation.

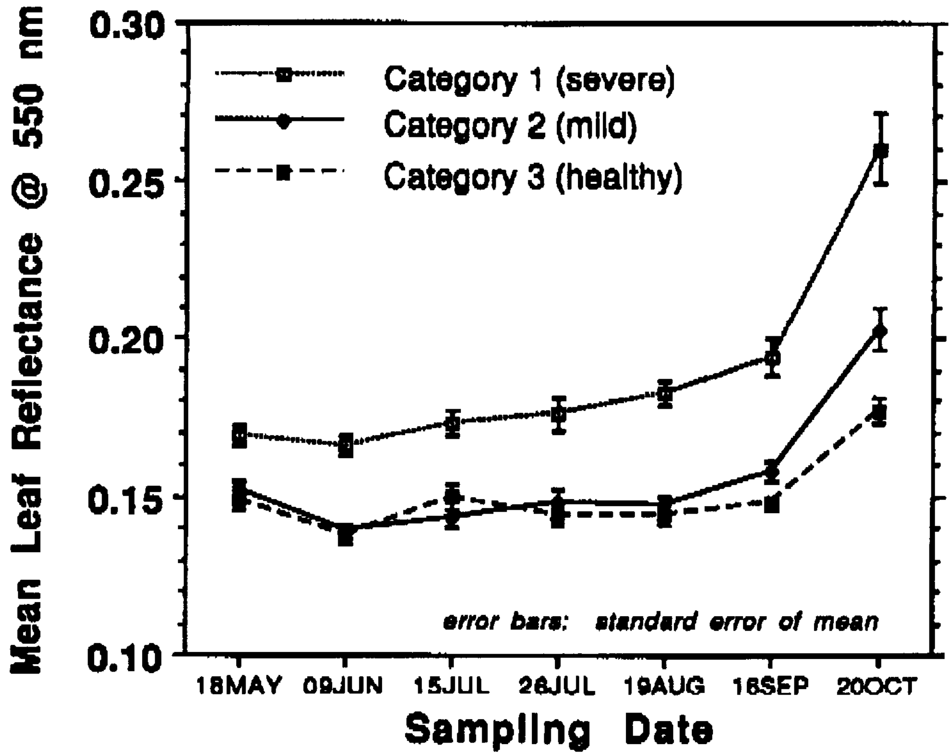

Figure 2: Green Peak reflectance by category over 1993 growing season.

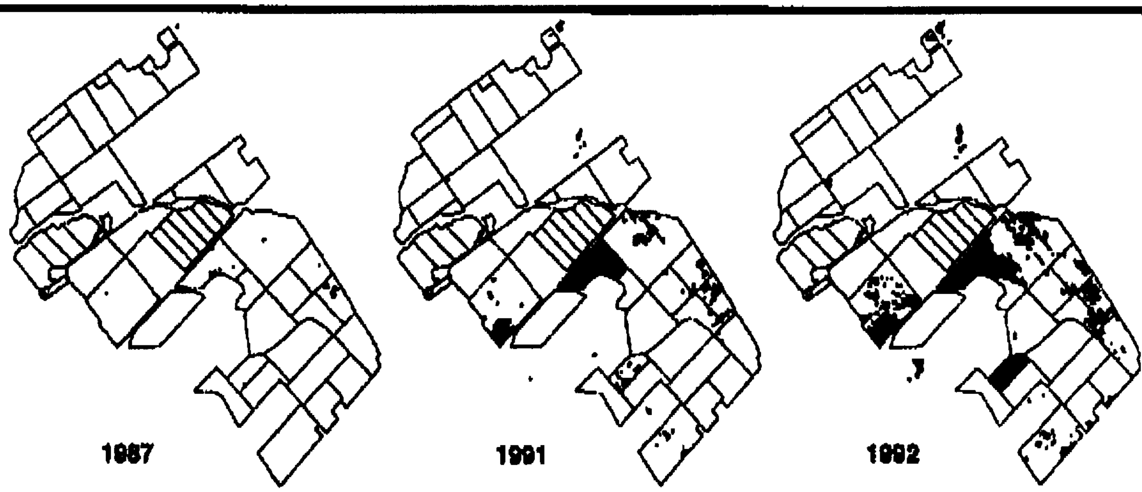

Figure 3: Phylloxera infestation in 1987, 1991, and 1992 demonstrating the rapid spread pattern for a study site.